New Trends in Automotive Mobility
Electric Drive Train

Overview

Batteries → Power Electronics → Electric Motor → Road, Vehicle Dynamics

Battery Management System
<table>
<thead>
<tr>
<th>type of batteries</th>
<th>energy density</th>
<th>power density</th>
<th>life time</th>
<th>cost</th>
<th>source: Braess, Seiffert</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wh/kg</td>
<td>W/kg</td>
<td>cycles</td>
<td>years</td>
<td>€/kWh</td>
</tr>
<tr>
<td>lead</td>
<td>30-35</td>
<td>200-300</td>
<td>300-400</td>
<td>2-3</td>
<td>100-150</td>
</tr>
<tr>
<td>nickel-cadmium</td>
<td>45-50</td>
<td>80-175</td>
<td>&gt;2000</td>
<td>3-10</td>
<td>&lt;600</td>
</tr>
<tr>
<td>nickel metal hydride</td>
<td>60-70</td>
<td>200-300</td>
<td>&gt;2000</td>
<td>10</td>
<td>300-350</td>
</tr>
<tr>
<td>sodium nickel chloride</td>
<td>90-100</td>
<td>160</td>
<td>1000</td>
<td>5-10</td>
<td>&lt;300</td>
</tr>
<tr>
<td>lithium-ion</td>
<td>90-150</td>
<td>500-700</td>
<td>&gt;1000</td>
<td>&gt;5</td>
<td>300-600</td>
</tr>
<tr>
<td>lithium polymer</td>
<td>110-130</td>
<td>ca. 300</td>
<td>&lt;600</td>
<td>k.A.</td>
<td>300</td>
</tr>
<tr>
<td>zinc air</td>
<td>100-220</td>
<td>ca. 100</td>
<td>k.A.</td>
<td>k.A.</td>
<td>up to 100°C</td>
</tr>
<tr>
<td>supercaps</td>
<td>5</td>
<td>1000-5000</td>
<td>500000</td>
<td>10</td>
<td>not rechargeable</td>
</tr>
</tbody>
</table>

source: Braess, Seiffert

**Electric Drive Train**

**Comparison of battery types**

**Cylindrical type**

- 1: Positive pole
- 2: PTG (Plexus Temperature Coefficient kit)
- 3: Socket
- 4: Collector
- 5: Positive pole
- 6: Negative pole
- 7: Separator
- 8: O2 channel
- 9: Cold start
- 10: Tipper

**Prismatic type**

- 1: Internal terminal
- 2: Sealing cap
- 3: Expansion film
- 4: Seal
- 5: Positive pole
- 6: Collector
- 7: Negative pole
- 8: O2 channel
- 9: Cold start
- 10: Tipper
- 11: Tipper
- 12: Positive cap

Source: [https://eu.industrial.panasonic.com/sites/default/files/3d_illustration_3d.png](https://eu.industrial.panasonic.com/sites/default/files/3d_illustration_3d.png) and [http://www.batteryuniversity.com/_img/content/pouch22.jpg](http://www.batteryuniversity.com/_img/content/pouch22.jpg)
Electric Drive Train
Battery Technology is the key technology

Tesla builds battery factory in Nevada (together with Panasonic)

50 GWh in annual battery production by 2020
Enough for 500,000 Tesla cars
Powered by renewable energy
Net zero energy factory


Ongoing discussion within Volkswagen group about the strategy

VW-Chef Müller zur Batteriefertigung

So einen Blödsinn machen wir sicherlich nicht

VW-Chef Matthias Müller stellt sich strittig gegen eine eigene Batterieproduktion des Autobauers, mehrt das Handelsblatt.

VW-Betriebsratschef: Wir müssen Batterien bauen

Der Trend hin zu Elektromobilität gefährdet viele Arbeitsplätze von Volkswagen. Betriebsratschef Osterloh spricht deshalb eine Drohung aus.

http://www.faz.net/aktuell/wirtschaft/unternehmen/osterloh-besteht-auf-bau-einer-batteriefabrik-14486729.html

source:
http://www.faz.net/aktuell/wirtschaft/unternehmen/osterloh-besteht-auf-bau-einer-batteriefabrik-14486729.html

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Electric Drive Train
Battery Technology is the key technology

In 2015, Daimler stops producing own lithium-ion cells, but …


Daimler stops producing own lithium-ion cells, but invests in Deutsche Accumotive

Source: http://www.business-on.de/dateien/bilder/accumotive.jpg
Types of electric motors für electric vehicles:

direct current motor
- series-characteristic motor
- shunt-wound motor

three-phase ac motor
- asynchronous motor
- synchronous motor
  - permanently excited synchronous motor
  - separately excited synchronous motor

special motors
- brushless dc motor
- transversal flux motor
- switched reluctance motor

Criteria in the selection of the motors

compact construction,
light weight (high power density),
High efficiency,
easy controllability in a wide speed and torque range,
overload,
low noise,
low cost, and
low maintenance requirements.
Electric Drive Train
Permanent-magnet DC Motor

basic structure

armature

source: upload.wikimedia.org/wikipedia/commons/a/a8/Gleichstrommaschine.svg
de.wikipedia.org/wiki/Gleichstrommaschine#mediaviewer/File:Kommutator_universalmotor_stab.jpg

turn rate $\omega = f(U_A, M)$

source: Roddeck, Einführung in die Mechatronik
Electric Drive Train
DC Motor: Pulse Width Modulation of the Armature Voltage

source: Roddeck, Einführung in die Mechatronik

Electric Drive Train
DC Motor: using an H-bridge

source: www.polulu.com BASIC-Tiger Application Note No. 059
Electric Drive Train
DC Motor: using an H-bridge as part of the Ekart drive train

source: Millipak 4CPM Controller Manual V1.01

Ansteuerung des L293D mit TTL-Signalen
M1 oder M2

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>links</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>rechts</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>normaler Stop</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>sofortiger Stop</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

source: www.skilltronics.de
Electric Drive Train
Synchronous motor

source: www.kfz-tech.de/Programme/GBild.htm?Bilder/Kfz-Technik/AltAntriebe/GAnimation02.gif

Electric Drive Train
Synchronous motor

source: www.vem-group.com/fileadmin/content/pdf/Download/Kataloge/Kataloge/pm_de.pdf
Electric Drive Train
Synchronous motor: Brushless DC- Motor

Brushless DC Motor Control

Electric Drive Train
Power electronics driving a synchronous motor

Three-phase ac motors are commonly used today in electric vehicles. Power electronics converts the dc voltage of the traction battery into ac voltages with variable amplitude and frequency.

source: http://www.mpowenuk.com/motorsbrushless.htm
der-schweighofer.at Elektromotor Motor Blade SR, Blade 200 SR X etc.
Electric Drive Train
Asynchronous motor

source: www.xplore-dna.net/mod/page/view.php?id=249
http://www.hgaechter.ch/elmaschinen/asyncmotor.htm

Electric Drive Train
Asynchronous motor: turn rate vs. torque

source: Roddeck, Einführung in die Mechatronik
Electric Drive Train

The Drive Train

- Traction battery with battery management and the required charger
- Electric motor with electronic control (inverter) and cooling
- Optionally necessary gear and a differential
- Power transmission to the driving wheels

Ancillaries: steering and braking assistance, heating and air conditioning system

Charging Dock or on-board charger

Variants of the powertrain:

- Vorder- oder Hinterrad-antrieb
- Tandem-antrieb
- Radnaben-antrieb

Electric Drive Train

Example: BMW i3

Source: www.bloomberg.com/bw/articles/2013-11-21/bmw-bets-on-carbon-fiber-bodies-for-cars
Electric Drive Train
Example: BMW i3

Electric Drive Train
Example: BMW i3
Electric Drive Train
Example: BMW i3

Lithium-Ion battery
Capacity of 22 Kwh
125 kW/170 hp electrical motor
Rear wheel drive
Acceleration: 0-60mph in 7.2 s
Top speed: 150 km/h
Range: 130 - 160 kilometer

Range Extender:
Gasoline engine drives a generator, range up to 340 km

35,000 – 40,000 €
Electric Drive Train
Example: Tesla Model S

Source: https://upload.wikimedia.org/wikipedia/commons/c/c3/2013_Tesla_Model_S_%2811322176214%29_cropped.jpg

Electric Drive Train
Example: Tesla Model S 2016

source: https://www.tesla.com/en_GB/models?redirect=no

Electric Drive Train
Example: Tesla Model S drive train

source: https://commons.wikimedia.org/wiki/File:Tesla_Motors_Model_S_base.JPG
Electric Drive Train
Example: Tesla Model X

Electric Drive Train
Example: Tesla Model X

Performance

<table>
<thead>
<tr>
<th></th>
<th>P90D</th>
<th>90D</th>
<th>75D</th>
<th>60D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>290 miles (NEDC)</td>
<td>202 miles (NEDC)</td>
<td>250 miles (NEDC)</td>
<td>220 miles (NEDC est.)</td>
</tr>
<tr>
<td>Acceleration</td>
<td>3.2 seconds 0-60 mph (Ludicrous)</td>
<td>4.8 seconds 0-60 mph</td>
<td>6.0 seconds 0-60 mph</td>
<td>6.0 seconds 0-60 mph</td>
</tr>
<tr>
<td>Torque</td>
<td>713 lb-ft (Ludicrous)</td>
<td>486 lb-ft</td>
<td>387 lb-ft</td>
<td>387 lb-ft</td>
</tr>
<tr>
<td>Top Speed</td>
<td>166 mph</td>
<td>166 mph</td>
<td>130 mph</td>
<td>130 mph</td>
</tr>
<tr>
<td>Motor Power</td>
<td>533 hp (Ludicrous) *</td>
<td>417 hp *</td>
<td>299 hp front and rear</td>
<td>299 hp front and rear</td>
</tr>
</tbody>
</table>

* Ludicrous mode

source: https://www.tesla.com/en_GB/modelx

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Electric Drive Train
Example: Nissan LEAF

1. RAPID CHARGER
30 MINS. Go from 0-80% in approximately half an hour; rapid charging is the fastest battery boost available, making long and longer trips possible. The national network of rapid chargers is expanding all the time, for example at Nissan dealers and motorway service stations.

2. HOME CHARGING UNIT
4-8 HOURS. Charge your Nissan LEAF overnight using a Home Charging Unit and reach full charge in approximately 8 hours, or even 4 hours with the optional 6.6kW on-board charger. Be sure to have your Home Charging Unit installed by an approved electrician.

3. CABLE + DOMESTIC PLUG
12 HOURS. Use your Nissan LEAF cable to charge your LEAF where you like – at a public charging stations, at work or at home (as long as the domestic socket is on a professionally installed dedicated circuit). Providing 10A power, it will charge from empty to full in approximately 12 hours.

http://www.nissan.co.uk/content/dam/services/gb/brochure/Leaf%20Brochure.pdf
Electric Drive Train
Example: Nissan LEAF: software

- Charging Station: Monitor details of all the nearest charging stations while you're driving.
- Pure Planning: Plan your trip from your PC or smartphone and send it to your Nissan LEAF.
- Autonomous Driving: One click on the steering wheel and autonomous cars reach your destination.
- Remote Charging: Charge your Nissan LEAF from your PC or smartphone. Also check the battery charge level and the remaining range.
- Eco Driving Champion: Join our global community of eco-drivers and gain your own social score.

Electric Drive Train
Example: Nissan LEAF: how do you sell this car?

<table>
<thead>
<tr>
<th>Doorstep</th>
<th>Grade</th>
<th>Engine</th>
<th>Transmission</th>
<th>Basic</th>
<th>VAT</th>
<th>Total Retail Price</th>
<th>On The Road Price</th>
<th>On The Road Price after Government Incentive*</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 door</td>
<td>VISIA</td>
<td>80kW AC Electric Motor</td>
<td>Single Reduction Gear (Auto)</td>
<td>21,105.00</td>
<td>4,323.50</td>
<td>25,428.50</td>
<td>25,428.50</td>
<td>25,428.50</td>
</tr>
<tr>
<td></td>
<td>ACENTA</td>
<td>80kW AC Electric Motor</td>
<td>Single Reduction Gear (Auto)</td>
<td>27,828.63</td>
<td>4,799.17</td>
<td>32,627.80</td>
<td>32,627.80</td>
<td>32,627.80</td>
</tr>
<tr>
<td></td>
<td>TENERA</td>
<td>80kW AC Electric Motor</td>
<td>Single Reduction Gear (Auto)</td>
<td>29,392.50</td>
<td>5,077.50</td>
<td>34,469.00</td>
<td>34,469.00</td>
<td>34,469.00</td>
</tr>
</tbody>
</table>

Basic and total road price includes delivery to dealership and number plates. On the road price includes £2,000 government grant which is applied to LEAF sales between January 2011 and May 2015.
Electric Drive Train
Example: Nissan LEAF: how do you sell this car?

NEW LEAF FLEX - (Battery Leasing)

<table>
<thead>
<tr>
<th>Description</th>
<th>Grade</th>
<th>Engine</th>
<th>Transmission</th>
<th>Basic</th>
<th>VAT</th>
<th>Total Retail Price</th>
<th>On The Road Price</th>
<th>On The Road Price after Government Incentive</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 door</td>
<td>NISSAN FLEX</td>
<td>80kW AC Electric Motor</td>
<td>Single Reduction Gear (Auto)</td>
<td>17,440</td>
<td>3,493.17</td>
<td>20,933</td>
<td>20,590</td>
<td>15,890</td>
</tr>
<tr>
<td>5 door</td>
<td>ADVANCED FLEX</td>
<td>80kW AC Electric Motor</td>
<td>Single Reduction Gear (Auto)</td>
<td>19,526</td>
<td>3,905.63</td>
<td>23,431</td>
<td>23,135</td>
<td>18,635</td>
</tr>
<tr>
<td>5 door</td>
<td>TEKNA FLEX</td>
<td>80kW AC Electric Motor</td>
<td>Single Reduction Gear (Auto)</td>
<td>21,195</td>
<td>4,239.17</td>
<td>25,434</td>
<td>25,139</td>
<td>20,639</td>
</tr>
</tbody>
</table>

Basic and Total Retail Price includes delivery to the dealership and number plates. On the road price excludes RMI government first registration fee.

*Government applied Ultra Low Carbon Car Consumer Incentive (deferred as Government Incentive) of £3,000 can be applied to LEAF sales between January 2011 and May 2011.

**Price includes obligatory monthly battery rental.

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Electric Drive Train
Example: VW e-up!

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100 km/h:</td>
<td>12.4 s (gasoline 13.2 s)</td>
</tr>
<tr>
<td>Torque:</td>
<td>210 Nm (gasoline: 171 Nm)</td>
</tr>
<tr>
<td>Electrical motor:</td>
<td>60 kW/82 hp (gasoline: 55 kW/75 hp)</td>
</tr>
<tr>
<td>Battery:</td>
<td>Lithium-Ion battery with 18.7 kWh</td>
</tr>
<tr>
<td>Range:</td>
<td>160 km</td>
</tr>
<tr>
<td>Weight:</td>
<td>1130 kg (gasoline: 1030 kg)</td>
</tr>
<tr>
<td>Cost:</td>
<td>less than 3€ / 100 km (gasoline: 6,68 € / 100 km)</td>
</tr>
</tbody>
</table>

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http://www.nissan.co.uk/content/dam/services/gb/brochure/Leaf%20Brochure.pdf
Electric Drive Train
Example: Mitsubishi iMiEV

Electric Drive Train
Example: Renault Zoe
Electric Drive Train
Example: Renault Zoe

Motor: 3-phase synch. motor
Battery: Lithium-Ion
Battery capacity: 22 kWh/65 Ah
Continuous power: 43 kw (58 hp)
Max. power: 65 kw (88 hp)
Max. torque: 220 Nm
Max velocity: 135 Nm/h

Front wheel drive
Range: 184 km
Price: 21.700 € (+ 79 €/month rent for the battery)
Electric Drive Train
Example: Renault Twizy
**Electric Drive Train**

*Example: FIA Formula E*

**2014–15** 11 races held in 10 different cities

All teams were supplied with the Spark-Renault SRT 01E (chassis by Dallara, electric motor by McLaren, battery system by Williams, tyres by Michelin)

**2015–16** 10 races in 9 different cities. For this season eight manufacturers were allowed to develop new powertrains.

**2016–17** new season starts in October 2016


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**Electric Drive Train**

*Example: Audi starts in Formula E*

**2016-17 season:** Audi expands its partnership with Formula E Team ABT Schaeffler Audi Sport

**2017-18 season:** Audi also announced plans to launch its own factory-backed motorsport program

Electric Drive Train

Example: FIA Formula E Roborace

motor racing series for driverless cars
Part of the Formula E championship support package from the 2016-17 season.

From carmagazine.co.uk:
“The organisers say the series will showcase the safety of autonomous cars and their potential ability to perform extreme manoeuvres when required, helping to build public confidence in driverless technology in the process.”


Electric Drive Train
... is a very old idea!

1859 Raymond Louis Gaston Planté invents the rechargable lead accumulator
1866 Werner von Siemens invents the DC motor with electromagnet
1881 Gustave Trouvé presents an electrical car on a trade show in Paris, that is fully operational and suitable for everyday use
1860 Christian Reithmann and 1862 Alphonse Beau de Rochas file patents for a four cycle engine
1876 the Otto motor is introduced to the market
1886 Karl Friedrich Benz files a patent for a vehicle with a combustion engine
1892 Rudolf Diesel files a patent for a „Neue rationelle Wärmekraftmaschine“
In 1899, Camille Jenatzy set a speed record with „La Jamais Contente“ of more than 100 km/h, exactly 105,882 km/h.
(2 motors with 25 kW each)

Electric Drive Train
… is a very old idea!

source: www.wikipedia.de

Electric Drive Train
History: Lunar Roving Vehicle

4 wheel hub motors, 200 W each,
2 motors for steering, 100 W each,
2 silver zinc potassium hydroxide batteries 36V with 121 Ah

source: www.wikipedia.org
Electric Drive Train
History: Electric Cars of the ’90s

Electric Drive Trains in everyday life
**Electric Drive Train**

**Electric Drive Trains in everyday life**

[Images of electric trains]

Sources: www.wikipedia.de

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**Electric Drive Train**

**History: Tesla Roadster**

[Image of Tesla Roadster]

215 kW (292 hp), 370 Nm - 400 Nm
0-60 mph in 3.7 s
Vmax 125 mph (201 km/h)

Sources: www.teslamotors.com

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Electric Drive Train
Big companies try out the „new“ idea of electric drive trains